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# Pump Drainage of the University of Wisconsin Marsh

G. R. B. ELLIOTT, E. R. JONES and O. R. ZEASMAN

AGRICULTURAL EXPERIMENT STATION
OF THE UNIVERSITY OF WISCONSIN

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# Pump Drainage of the University of Wisconsin Marsh

G. R. B. Elliott, E. R. Jones and O. R. Zeasman

The farm of the Agricultural Experiment Station of the University of Wisconsin contains about 130 acres of low land adjacent to Lake Mendota. The surface of nearly 80 acres of this is lower than the lake. In 1910 this surface was level with the lake, rising and falling as the lake rose and fell. It was a "floating" bog or a "lake-level" marsh.

Since then, all but about 5 acres left for comparison has been tile drained. An electrically driven, automatically controlled pump, lifting water 7 feet out of a reservoir into the lake, furnishes the outlet. Lines of tile generally 4 rods apart, from 3 to 5 feet deep, and discharging into mains that lead to the reservoir, effect the internal drainage. A turnpike along the lake acts as a dike to keep back the lake water. A ditch and a dike surrounding the low area act like an eave trough to catch the surface water from the surrounding hills and carry it to the lake without pumping. This diversion ditch is to protect the area so that only the seepage from the hills and the lake and the rainfall normal to the tract has to be pumped.

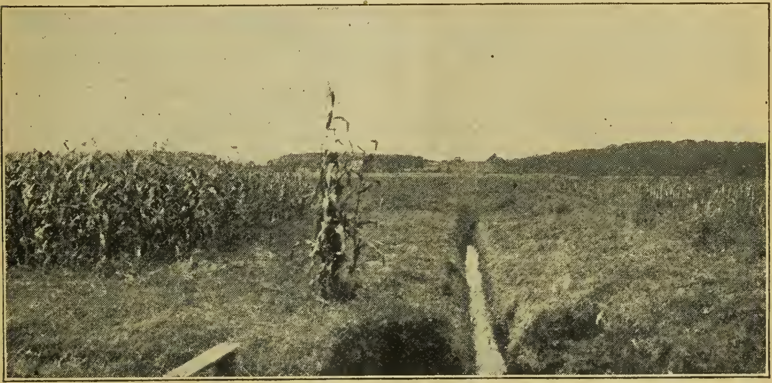


FIG. 1.—FROM CAT-TAILS TO CORN.

The marsh on the right of the ditch shows its original condition.

The area is a true peat bog of the alkaline type. The peat is from 1 to 6 feet deep and lies on a thin bed of marl which in places blends into silt or clay, varying in thickness up to 18 inches. Beneath the silt or clay is water-bearing sand in some places interbedded or intimately mixed with shell marl. So great was the artesian pressure in this sand that water would rise in a pipe 2 feet or more above the surface of the marsh.

The drainage of this marsh was started in 1910. This is a report of the experience of ten years that has resulted in the present drainage system. The drainage is now such that good crops of corn, buckwheat, timothy and alsike are harvested even in wet years.

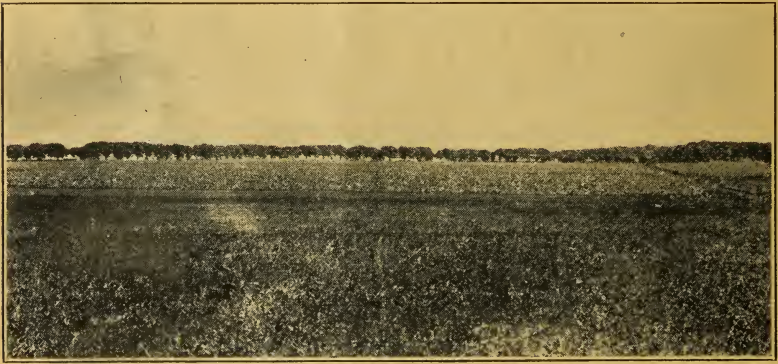


FIG. 2.—HOW THE MARSH LOOKS

About 80 acres of the drained portion of the marsh is shown, crops of 1920. The lake is immediately beyond the row of willow trees in the background.

## OPEN DITCHES FAILED

This tract has given us a splendid opportunity to carry on experimental work in drainage. A record of the mistakes as well as successes is worth reading from the experimental point of view. In 1910, open ditches were dug 16 rods apart over about 80 acres. They were 1 foot wide at the bottom, 4 feet deep, and 5 feet wide at the top, but lateral pressure in the wet soil soon narrowed the top width to about 3 feet. The soil was so peaty that the slopes have stood up well. In one ditch that has not been filled up, the spade marks ten years old are still visible on the slopes. Nevertheless, the sides undermined and broke off in places. Particles of floating peat lodged against weeds, straws, or sticks that found their way into ditches, so that the ditches had to be cleaned out about once a month. All of these ditches, aggregating 880 rods, were connected with the reservoir from which the water was pumped into the lake.

It was hoped that these ditches would permit the soil to settle and become firm and dry, so that the wild marsh grass could be harvested where the cat-tails and willow brush were not too thick. The wire grass, and in places the blue joint, grew luxuriantly but the ground was too soft and wet for horses. They mired within 10 feet of the empty ditches even when wearing bog shoes. The more valuable grass was cut with a scythe and carried off on poles. The rest was not cut at all.

## WIND AND GASOLINE FAILED

A geared windmill was erected to run a bucket water elevator. A 16-inch reverse-turbine pump was installed to supplement the

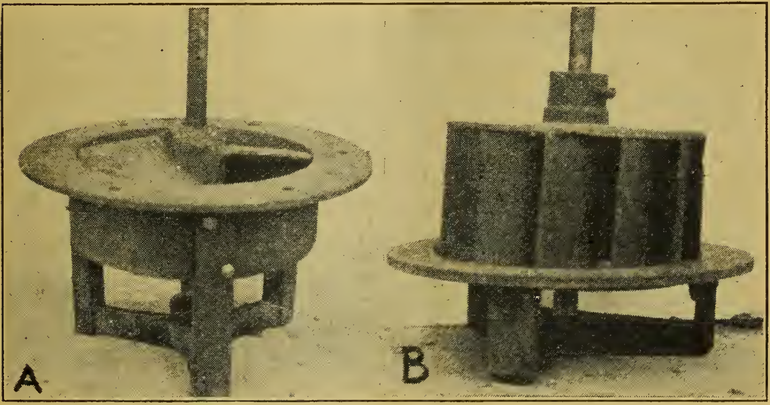


FIG. 3.—A. THE AUGER PUMP

Its big advantage is that sticks or other debris do not clog it. Its efficiency is about 40 per cent with 600 revolutions per minute lifting 2780 gallons per minute 5 feet high and requiring a 9 to 13 h. p. motor. Lower speed gives less efficiency.

B. THE REVERSE TURBINE-PUMP

An efficiency of 40 per cent has been recorded with 400 revolutions a minute, lifting 2780 gallons per minute 5 feet high and requiring an 8 to 10 h. p. motor.

elevator. This was run by a 12 h. p. gasoline engine. In 1910 the lift was about 5 feet. It was soon evident that the amount of water lifted by the windmill and elevator was small in comparison to that which had to be pumped and the wind power was abandoned after a trial of about two months. An attendant started the gasoline engine and turbine pump and emptied the ditches regu-

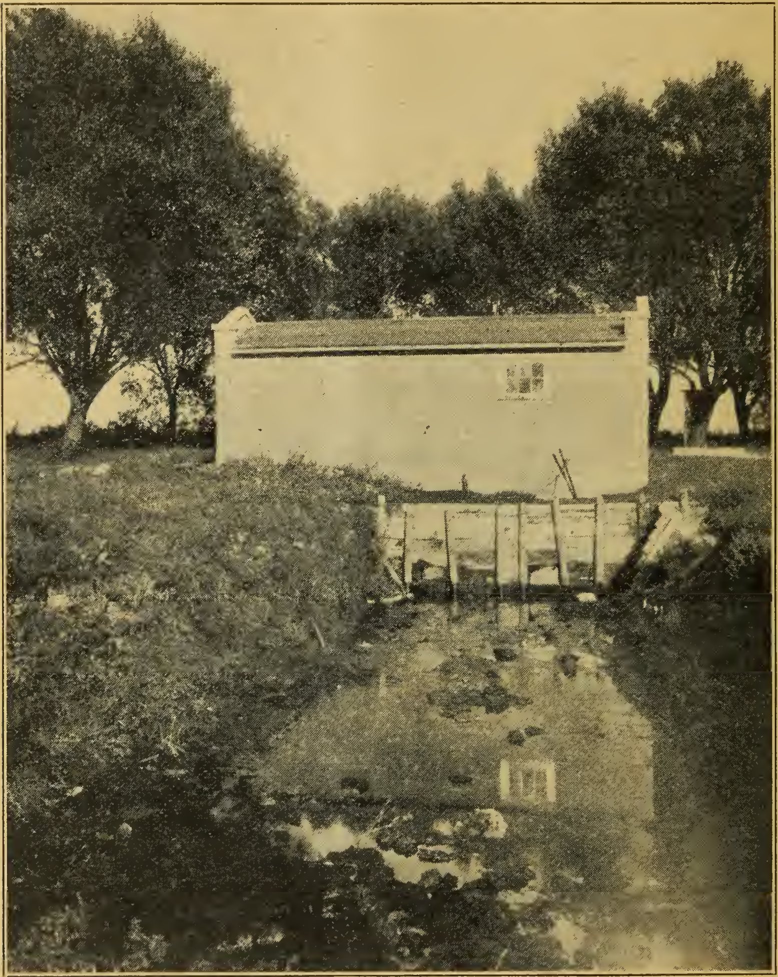


FIG. 4.—THE PUMP HOUSE

The foundation had to be heavily reinforced because of the soft footing. The crack in the wall is due to pouring the concrete at different times.

larly three times a day, the last being at 5 o'clock. By the next morning the water in the ditches would be within a few inches of the top. The pump would empty the ditches, aggregating 880 rods in about an hour, ordinarily. During rainy weather the pump was started more frequently or was run for two hours or more at a time.

It soon became evident that the soil could not be made dry enough so long as the ditches were allowed to fill up with water during the night. It was too expensive to dig a reservoir any larger than 10 feet by 50 feet and this did not have enough storage capacity to last all night.

## ELECTRIC POWER AND DEEP TILE SUCCEEDED

The efficiency of frequent pumping and tiling was tested in 1914. With the aid of two students the gasoline engine and pump was started every three hours or oftener during the night; and a farm hand did the same during the day. The experiment began April 20, 1914, and continued for twenty days.

The students had previously laid two lines of 4-inch tile 300 feet long and 2 rods apart, one line being 1 rod from an open ditch. The gradient was .1 for each 100 feet. They were 3.0 feet deep at the outlet and about 2.5 at the head. The shallowness of the reservoir did not permit greater depth.

On May 8 the tiled plot was plowed with horses. This was the first plowing that had ever been possible on the lake-level marsh. A small portion at the upper end of the lines of tile where the water table in the observation holes came within 2 feet of the surface of the ground was too wet even then to hold up the horses.

The experiment proved that if the tile could be laid deep enough and if the pumping were done at such frequent intervals that the tile outlets did not become submerged, the lake-level marsh could be drained and plowed. The proposition seemed sufficiently feasible to warrant the installation of electric power which lends itself admirably to automatic control. A 10 h. p. electric motor was installed. A float on the water in the reservoir connected with a switch started the pump just before the tile became submerged

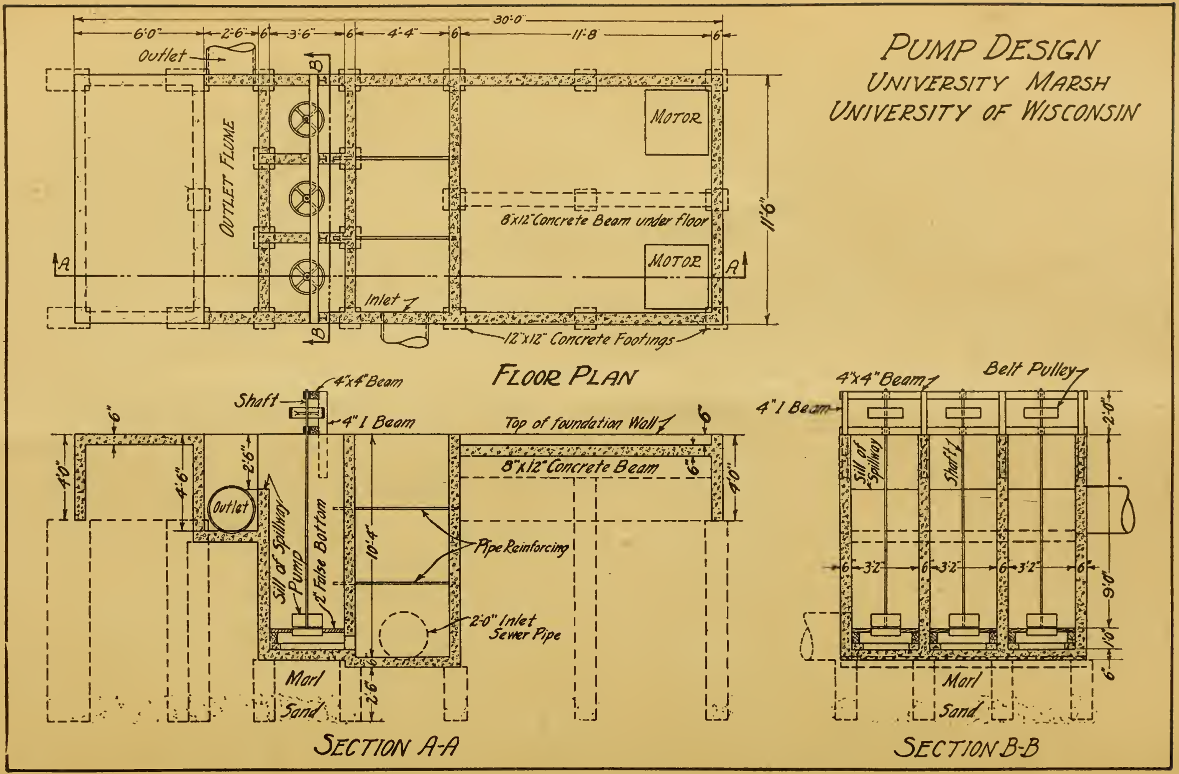


FIG. 5.—PLANNED FOR EMERGENCIES

There are three pump chambers with pumps installed in two of them, one for steady use and the others for emergencies. The foundation is deep enough to take care of future settling of the marsh.

and stopped it when the reservoir was empty. The reservoir was deepened a trifle and more tile were laid in 1914. From 7 to 15 acres has been tiled every year since that time.

For several years plots 16 rods wide had ditches on three sides of them in which the water was kept 3½ feet below the surface by pumping day and night. Yet they never became dry enough even during a summer drouth to permit the marsh grass to be mowed with horses. It was not until lines of tile 4 rods apart and about 4 feet deep were laid that satisfactory drainage resulted. Where the depth of the reservoir and pump limited the depth of the tile to 3 feet, the lines had to be 2 rods apart to permit plowing. Furthermore, the peat above the tile has shrunk with drainage and decomposition. Tile that formerly had 4 feet of peat over them now have only about 3 feet, and those that had 3 feet now have but little more than 2 feet. In 1919 the shallower reservoir was deepened again and these shallow lines are now being dug up and relaid at a greater depth—in some places 5 feet deep.

The Soils Department in 1919 and 1920 ran a series of tests on a portion of the marsh that was tiled in 1918. These tests show that the yield of corn can be raised from 34.5 to 83.5 bushels to the acre by proper fertilization.

A 24-inch breaking plow drawn by a tractor was found to be the best method of breaking the marsh. Thereafter a disc plow did better work than a mold-board plow because the latter would not scour due to the looseness of the soil.

Corn has proven to be the most satisfactory crop on the drained peat. Even the first year after drainage, good crops of corn result. This is fortunate because the University Farm requires a large area of corn within hauling distance to fill its silos. Timothy and alsike has proven to be a good crop where the tile were unable to cope completely with excessive seepage.

## DETAILS OF THE DRAINAGE SYSTEM

About 15 acres of the west end of the marsh was higher than the rest, it being from 4 to 7 feet above the normal lake level. It was a "springy" marsh kept wet by the seepage from

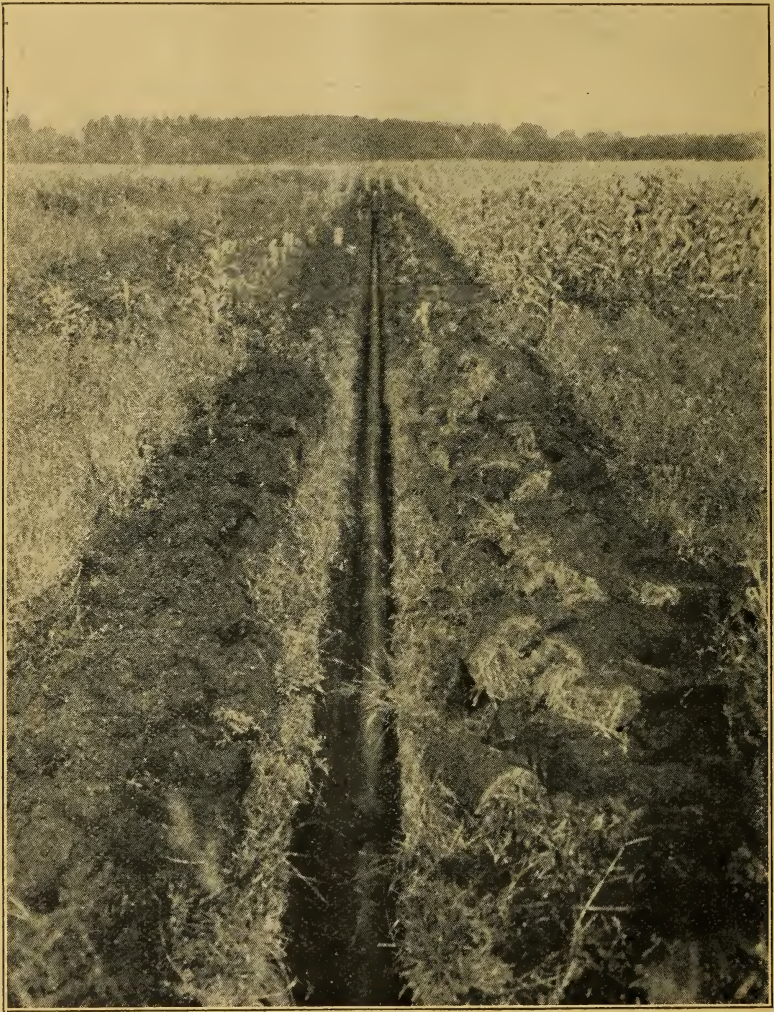


FIG. 6.—REPAIRING THE SYSTEM

The original tile drainage system had lines 4 rods apart. In some places it was necessary to put in lines later midway between the original lines. In other places where the lines were deeper and seepage was less, satisfactory drainage has resulted with lines 8 rods apart.

the upland. The parallel laterals of Group 1 were put in 4 rods apart to discharge into Main A. (See Fig. 11.) The laterals had a gradient of .1 in 100 and the main .05 in 100. While the laterals could not be put as deep as desired, they cut off the seepage fairly well. They collected enough water to fill the main at the outlet of Line 1, but little or none of the water reached the outlet. It leaked back into the soil along the main and entered the lower marsh from which it had to be pumped, thus defeating the original purpose which was to carry this seepage to the lake without pumping. Main A was dug up in 1915 and relocated to carry the water directly to the pump.

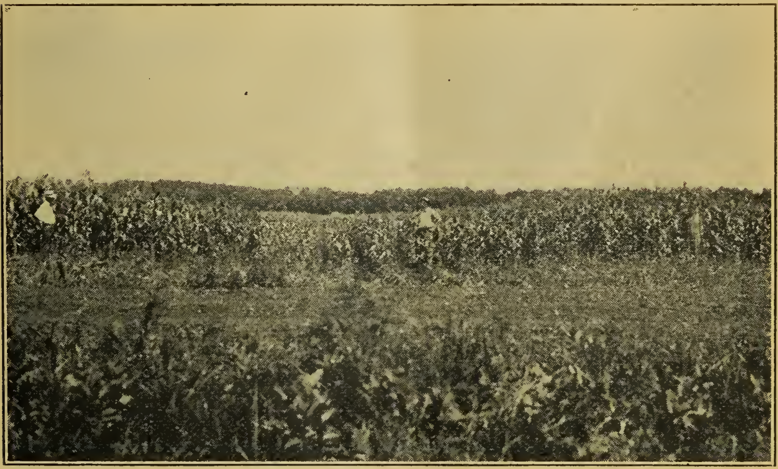


FIG. 7.—CORN POOR BETWEEN LINES OF TILE

Taken near the head of Lines 8 and 9 Group VIII before Line 29 was put in for relief.

The history of Main A taught two lessons: (1) A line of tile to cut off seepage effectively must have a liberal fall; and (2) when water is carried in a tile through a soil that would be otherwise dry, the roots of willow trees will enter the tile. To obtain enough soil to cover the tile properly it was located on land reasonably dry and about 4 feet higher than the lake. A willow tree had sent one root through a crack between two tile. This root sent out myriads of fibrous branches which after five years completely filled the 8-inch tile for about 15 feet above the point of entrance. This was not the direct cause of the failure of this main, however. The heavy leakage from this main back into the marsh was observed the first year after it was laid, or before the roots had had time to fill the tile.

The land drained by Group XI was the most difficult to drain. The soil was muck one foot deep lying on about three feet of clay under which there was water-bearing sand. To dry up the springs that broke through the clay, lines had to be put as close together as 10 feet in some places. When the 8-inch main was laid in 1916 it was put 5 feet deep. It was difficult but very effective to get this main down into the water-bearing sand. This so relieved the pressure that springs 4 rods away were dried up. Another effective device was a column of the vertical tile reaching from the bottom of the horizontal tile through the clay into the sand. This permitted the water to rise easily into the tile and escape, thus relieving the pressure that caused the springs.

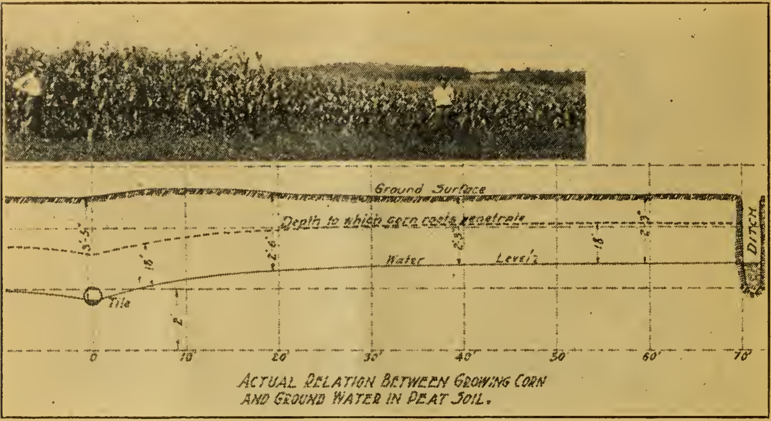

Ground Surface
Depth to which corn roots penetrate
Water Level
Tile
DITCH
18"
18"
0
10'
20'
30'
40'
50'
60'
70'
ACTUAL RELATION BETWEEN GROWING CORN AND GROUND WATER IN PEAT SOIL.

FIG. 8.—THE CORN SHORTENS AS THE WATER TABLE RISES

Taken between Line 1 Group VIII and the ditch at the side of Willow Drive.

It has been difficult to get protection at all times from the ditch and dike on the north and west side of the marsh. Sediment is deposited in it from the steep hillsides and it has to be cleaned with teams and scrapers once in two years. The ditch and dike are seeded to timothy, but when the grass is tall the flow during floods (it is dry the rest of the time) is retarded and some of the water overflows the dike. This dike has been more successful, however, than Cinder Drive, on the south side of which a ditch was originally dug to carry the flood water to the lake by gravity. This ditch was so nearly level that even in a small flood more water flowed over the drive near the outlet of Line 101 than flowed east into the lake. In 1916 another drive about half way up the hill on the south side of the marsh was raised so that it catches the surface water; and a ditch on its upper side carries

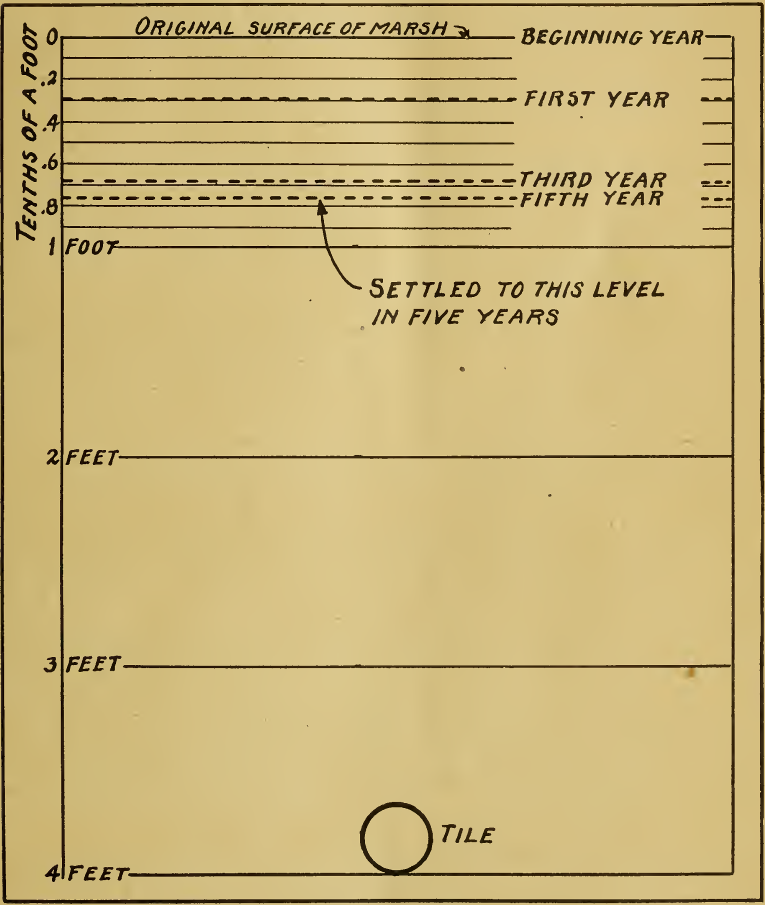


FIG. 9.—HOW THE PEAT SETTLED

The tile were originally between 3 and 4 feet below the surface of the peat. The shrinkage is confined almost wholly to the peat laying above the tile.

this water to a creek entering the lake. Line 117 has carried seepage better since it has been tapped by Line 103.

A glance at the map shows that in general the laterals of 4 or 5 inch tile are 4 rods apart, except where excessive seepage or limited depth made it necessary to put the lines 2 rods apart or closer. Generally the laterals do not exceed 40 rods in length. The mains are numerous and large enough to compensate for the limited gradient of .05 in 100, which puts them deep enough to afford the laterals a gradient of .1 or .2 in 100 and a depth of about 4 feet.

Measurements in 1914 showed that the third ditch from the lake carried more water than the first one. It appeared that the third ditch was receiving seepage both from the lake and from the upland. By 1920 it was evident that the line of tile nearest the lake carried more water than any other lateral on the marsh, and that the seepage from the lake was increasing. The Willow Drive, the turnpike diking off the lake, is merely built up about 2 feet above the surface of the marsh and nothing has ever been done to strengthen its foundation so as to stop seepage. Muskrats have burrowed beneath this drive and repeatedly these holes have had to be plugged.

## SURFACE, SOIL AND TILE EXAMINED

In the fall of 1919 the Agricultural Engineering Department undertook an investigation of the conditions then obtaining on the marsh for the purpose, if possible, of securing reliable fundamental information which might be of value in carrying out other reclamation work throughout the state. The investigation included a compilation into one system of all the notes and data on previous experimental work and a comparison drawn between original and recent conditions, particularly as to the shrinkage of the soil volume. The map (Figure 11) and Table 1 give the results in detail.

TABLE I.—SETTLING OF TILE AND SURFACE. ELEVATIONS IN 1920

| Lines | Date of laying | Number of stations | Average surf. elev. when laid | Average depth when laid | Surface settlement | Tile settlement |
|---|---|---|---|---|---|---|
| I—0 to 6 | 1910 | 64 | 854.5 | 3.07 | .406 | .107 |
| V—6 to 9 | 1919 | 15 | 848.8 | 3.79 | ---- | ---- |
| V—10 to 12 | 1919 | 9 | 849.4 | 3.51 | ---- | ---- |
| V—13 to 19 | 1918 | 21 | 848.8 | 3.71 | .298 | .189 |
| V—20 to 23 | 1916 | 25 | 848.7 | 3.76 | .680 | .081 |
| V—23 to 32 | 1916 | 33 | 849.8 | 3.83 | .591 | .008 |
| VII—1 to 7 | 1914 | 27 | 848.7 | 3.35 | .760 | .037 |
| VIII—6a | 1914 | 2 | 849.0 | 3.16 | .805 | .215 |
| VIII—7 to 16 | 1916 | 47 | 850.1 | 3.77 | .660 | .054 |

| Lines | Remarks |
|---|---|
| I- 0 to 6 | Peat or muck to 1.5; clay to 4.5; sand beneath |
| V 6 to 9 | Peat 4 to 6 feet. Settlement not measured |
| V-10 to 12 | Peat 4 to 6 feet. Settlement not measured |
| V-13 to 19 | Peat 4 to 6 feet. One Station Line 6 excluded |
| V-20 to 23 | Peat 4 to 6 feet. Seven stations of Line 23 |
| V-23 to 32 | Peat 2 to 4 feet. Five stations of Line 23 |
| VII- 1 to 7 | Peat 4 to 6 feet. Near pump house |
| VIII-6a | Peat 4 to 6 feet. Near pump house |
| VIII- 7 to 16 | Peat 4 to 6 feet. Receives upland seepage. Two stations Line 10, one station Line 11, and one station Line 15 excluded. |

Settlement of surface levels showed that the surface of Plot S (surface drained for six years but not tiled) had settled .4 feet below the marsh on the lake side of the drive that serves as a dike. While Plot S was too wet to plow, it did get enough drainage to change the character of its wild vegetation. The land tiled in 1914 had settled about .75 feet by 1920. Practically all of the shrinkage had taken place in the peat above the tile, and settling of the tile themselves was comparatively small. A comparison of the levels taken on the marsh surface in 1910 and 1914 when the automatically controlled pump was installed showed that there was practically no settlement during those four years of intermittent drainage.

The settlement varied with the seepage. Group V Lines 20 to 23 laid in 1916, underlaid by marl and water-bearing sand, and receiving much seepage showed more surface settlement than Group V Lines 24 to 32 laid in 1916, where the subsoil was clay and the seepage was less. The peat lying on the water-bearing sand was buoyed up by the pressure from below and the settlement was great when that pressure was relieved by drainage. Group VIII, Lines 4, 5, 6, 19 and 20, overlying submerged tongues of sand causing great seepage both from the lake and the hills, showed the remarkable surface settlement of nearly one foot in two years.

**Examination of Tile.**—Complete levels were run through the body of the marsh both on the surface of the ground and on the tile, using the same stationing as was used in laying out the original work. For the purpose of getting the grade of the tile, a steel rod of known length was thrust down onto the tile, care being taken that the rod rested on the top of the convex surface. Lines of tile were opened for the purpose of examining their condition. This was done for the most part in groups, a group consisting of tile of the same kind and laid under similar conditions. If two or three pits in a group showed no evidence of unusual conditions, the group was assumed to be uniform, but if any unusual conditions were exposed further openings were made in sufficient number to ascertain the facts and, if possible, their cause.

**Settlement of Tile.**—Only two groups of tile were found to be materially below grade. Group VIII Lines 4 to 20 averaged .25 feet in settlement of tile. In this group the greatest variation was shown by the levels to be on the outer ends of the lines where the marsh was narrow and subject to the most seepage. The last two stations of VIII Line 6 sank an average of .53 feet while the surface above sank 1.05 feet. Group VIII Line 19 sank .35 feet and the surface .95 feet. The uniformity of settlement in the outer ends of all the lines shows that the discrepancy was not due to any error in laying the tile or in the levels, but to a general subsidence when the water was drawn off.

Group V Lines 13 to 19 were laid by a careless contractor who got his ditches too deep in places. To remedy this defect the lower grade was carried through to the outlet. This alteration does not appear in the notes and the tile grades were thrown out.

**Rate of Settlement on Marsh Surface.**—The time over which the records extend is not sufficient to establish an absolute rate of settlement of the marsh surface, but there are sufficient data on which to base an estimate. This seems to be very close to .25 feet a year for the first two years. After this the rate drops off rapidly until at five years the total settlement has reached .76 and the rate of settlement about .04 feet (½ inch) a year but slowly decreasing. (The accompanying diagram Fig. 9 shows this more fully.) The settling for one year is the average of 21, for two years 44, for three years 105, and for five years 27 observations, the average depth of the tile when laid being about 3.7 feet.

**Decrease in Weight with Decay.**—In order to ascertain what became of the material which shrank away upon drainage, pits were dug—one in the cultivated portion (middle of Group VII), and the other in the untiled marsh (Plot S)—in order that the original conditions should be as nearly alike as possible. From these pits, samples were taken at intervals of a foot. Before the samples had time to dry they were cut into 6-inch cubes and carefully weighed. They were then dried to constant weight at 110°C and again weighed. The results are shown in Table II. The difference between the weights of the bottom samples is most remarkable and probably represents the mineral matter brought into the peat by ascending seepage waters. The last foot of the untiled soil was entirely

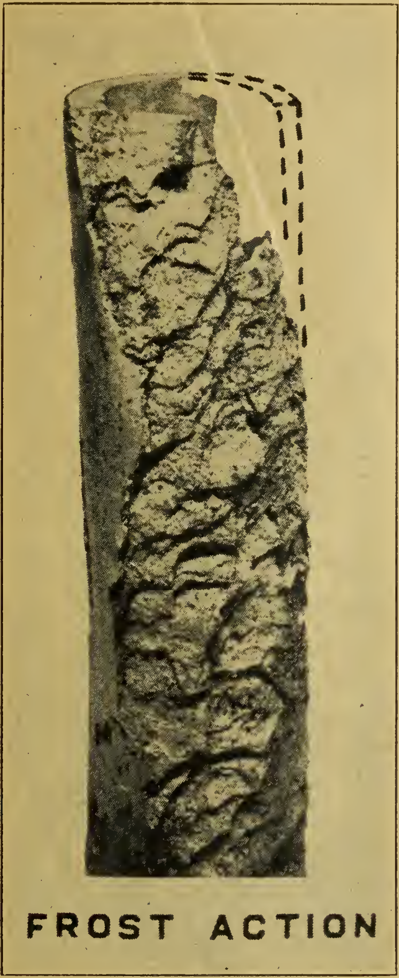


FIG. 10.—THIS TILE WAS ABUSED

A clay tile lying on the surface of the ground throughout the winter freezes and thaws suddenly a great many times. This splits the walls and the tile are damaged more in a single winter than they would be in 100 years if covered with 2 feet or more of earth.

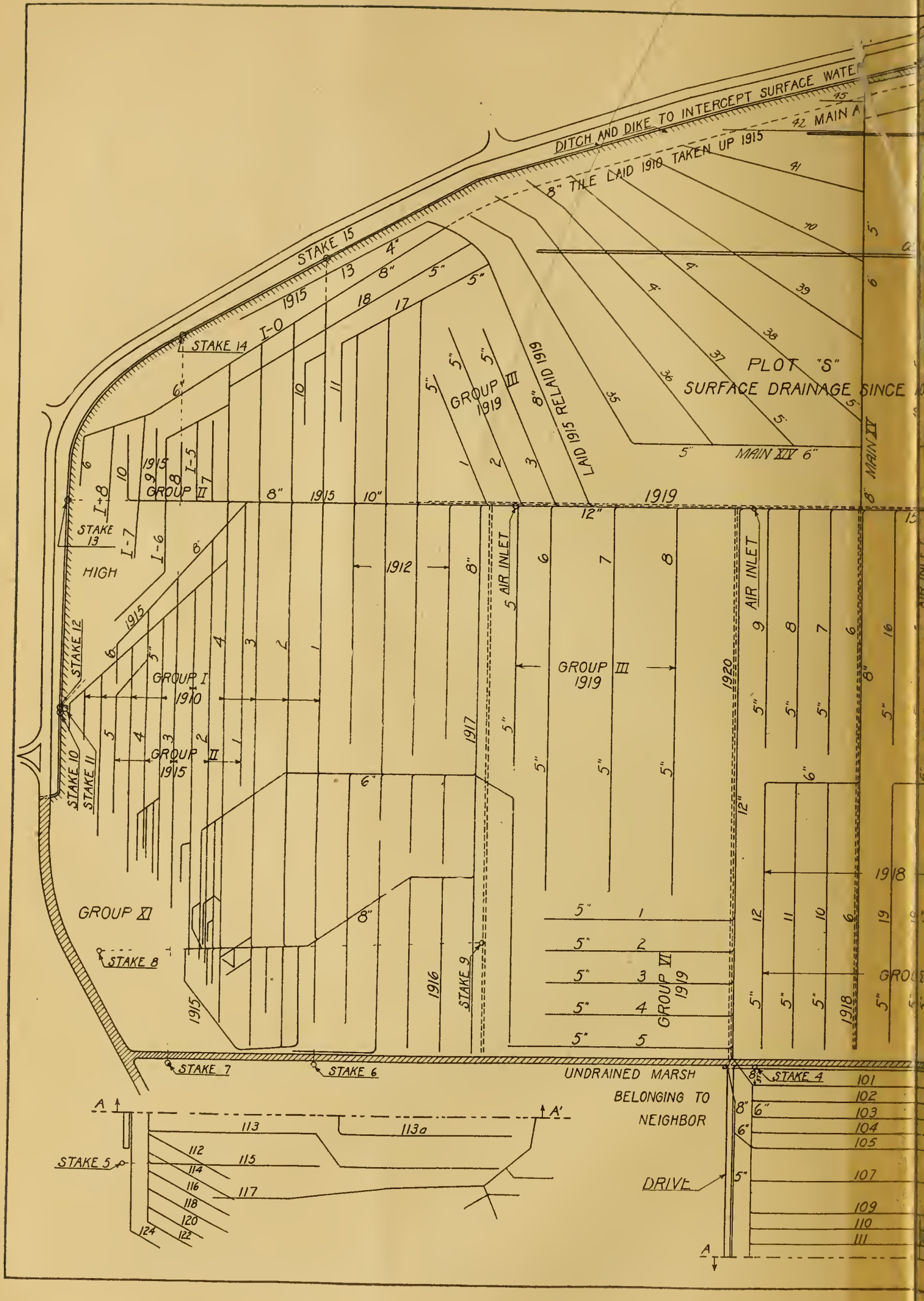
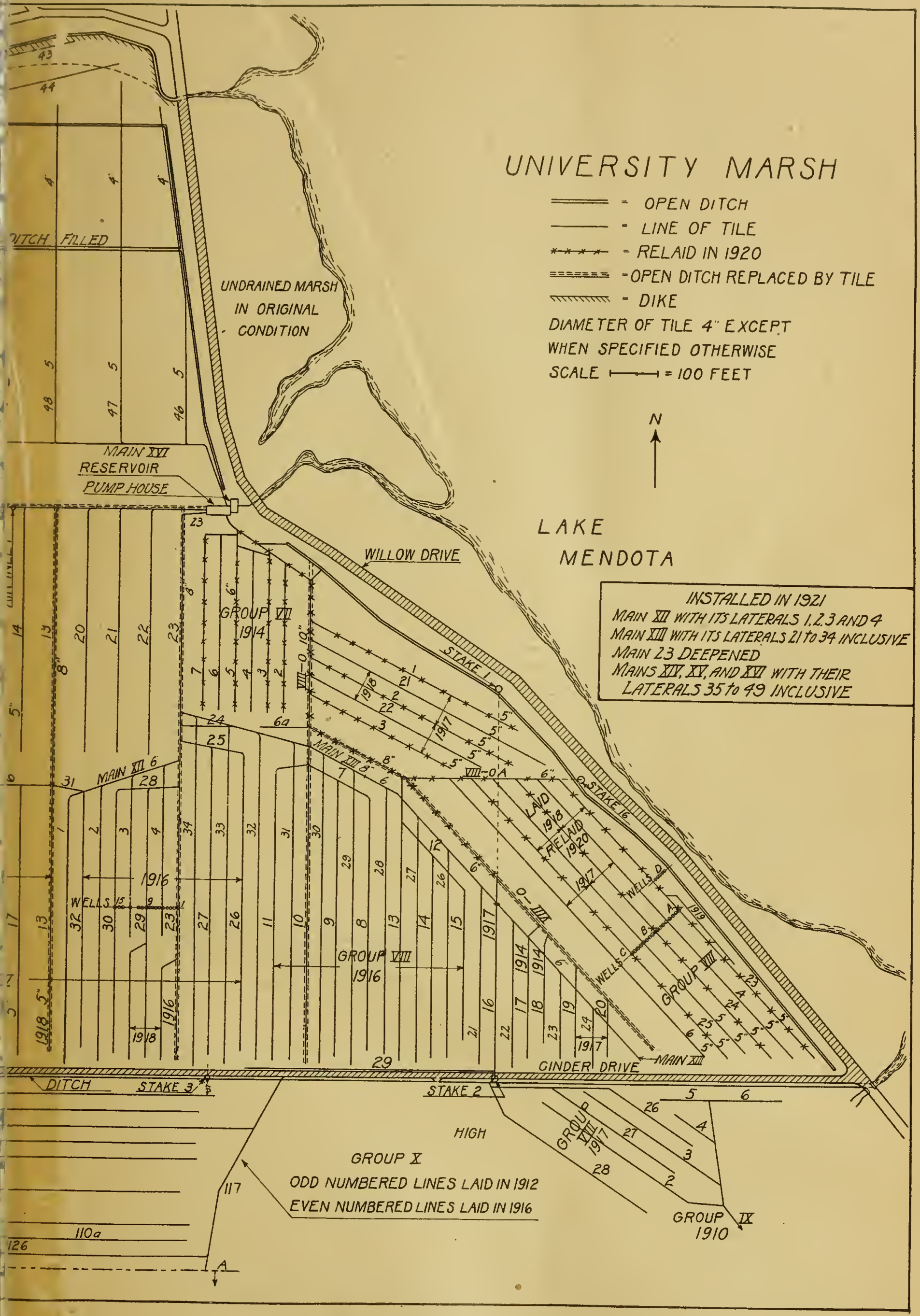


FIG. 11—MA

Note the reference stakes (iron pipes) that have been driven in convenient place



F MARSH

o help locate the principal lines of tiles. Others can be located from these.

## TABLE II.—WEIGHT OF WET AND DRY PEAT

| Section measured | Tiled and cultivated six years | | | | Untiled and uncultivated | | | |
|---|---|---|---|---|---|---|---|---|
| | Elevation in feet | Actual weight in lbs. per cubic foot | | Calculated weight of section in pounds | Elevation in feet | Actual weight in lbs. per cubic foot | | Calculated weight of section in pounds |
| | | Wet | Dry | | | Wet | Dry | |
| Top 4 ins. | 847.94 to 847.63 | 23.34 | 8.28 | 2.76 | 848.3 to 847.97 | 13.73 | 6.46 | 2.19 |
| 4 to 6 ins. | 47.63 to 47.44 | ----- | ----- | 1.40 | 47.97 to 47.81 | ----- | ----- | 1.41 |
| 6 to 12 ins. | 47.44 to 46.94 | 61.06 | 12.49 | 6.25 | 47.81 to 47.31 | 64.27 | 10.48 | 5.24 |
| 12 to 18 ins. | 46.94 to 46.44 | ----- | ----- | 6.59 | 47.31 to 46.81 | ----- | ----- | 5.65 |
| 18 to 24 ins. | 46.44 to 45.94 | 66.61 | 13.88 | 6.94 | 46.81 to 46.31 | 64.57 | 12.57 | 6.28 |
| 24 to 30 ins. | 45.94 to 45.44 | ----- | ----- | 6.85 | 46.31 to 45.81 | ----- | ----- | 6.30 |
| 30 to 36 ins. | 45.44 to 44.94 | 65.45 | 13.51 | 6.75 | 45.81 to 45.31 | 65.83 | 12.62 | 6.31 |
| 36 to 42 ins. | 44.94 to 44.44 | ----- | ----- | 7.29 | 45.31 to 44.81 | ----- | ----- | 6.28 |
| 42 to 48 ins. | 44.44 to 43.94 | 66.63 | 15.65 | 7.82 | 44.81 to 44.31 | 64.81 | 12.50 | 6.25 |
| 48 to 54 ins. | 43.94 to 43.44 | ----- | ----- | 7.83 | ---------------- | ----- | ----- | ----- |
| 54 ins. | ---------------- | Marl | ----- | ----- | ---------------- | ----- | ----- | ----- |
| 48 to 58½ ins. | ---------------- | ----- | ----- | ----- | 44.31 to 43.44 | 64.89 | 8.87 | 9.34 |
| 70 ins. | ---------------- | ----- | ----- | ----- | ---------------- | Marl | ----- | ----- |
| Weight of column above elevation 843.44 | | | | 60.48 lbs. | | | | 55.25 lbs. |

different in character from any other sample taken out. It was extremely soft and light buff in color, darkening to almost black within five minutes after exposure to the air. The column of tiled soil one foot square and extending from elevation 843.44 to the surface, seems to have retained its original weight fairly well even though it has lost in volume. The weight of each cubic foot or portion thereof was calculated from the actual weight of the 6-inch cube typical of it—except the surface 4 inches which was weighed separately.

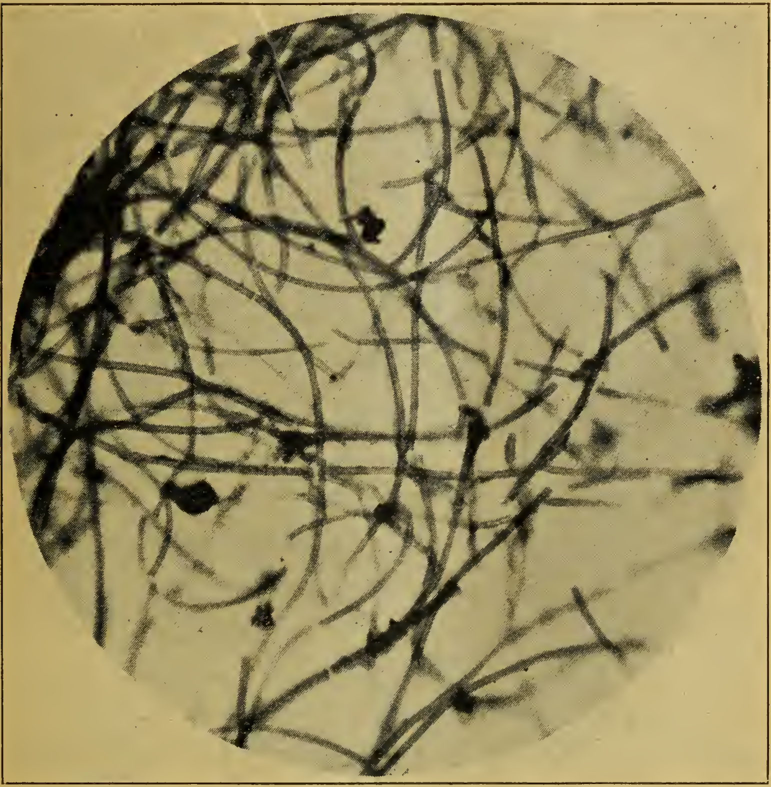


FIG. 12.—IRON BACTERIA THAT CLOG TILE

Leptothrix ochracea, from University Marsh. Colored with gentian violet. Magnified 650 times. The black masses are ferric hydroxide. In the tile they cause an accumulation of yellow slime.

**Frost Action on Tile.**—Four of the lines of tile laid in 1910 crossed the entire width of the marsh. Near the upper or southerly end the land dropped into a hollow or swale in which the clay was covered by about one foot of black muck. In order that the tile should not be too deep for the greater part of the distance the tile were necessarily shallow in passing through the low ground. In the interval since the tile were laid the black muck had entirely rotted away and disappeared leaving the tile less than a foot deep. Here they were exposed to repeated freezing and thawing and probably had been for years. The tile were of good clay and well burned. No trace of any failure or disintegration showed. At the outlet of the easterly main, where it enters the pump house reservoir, six feet of the 12-inch clay tile exposed to direct frost action scaled off and collapsed in two winters.

Even with a light covering the freezing takes place slowly; the entire wall of the tile is the same temperature and formation of ice crystals goes on uniformly. Any excess moisture which may develop, due to expansion of the freezing water, is permitted to escape through the partially frozen walls and no rupture takes place. Such ruptures do occur at an exposed outlet subject to sudden freezing. This is well illustrated by Figure 10. This was a 3-inch clay tile which was for ten years in an underdrain, then taken up in perfect condition and replaced by larger tile. It then lay on the ground for five winters with the result as shown. The upper surface is more than half scaled away while the lower side which lay on the ground and was protected from direct frost is still in nearly perfect condition.

**Iron Bacteria.**—While the work of examination of the marsh was going on an accident caused a stoppage of the pump. As the stoppage occurred during the night it was not noticed until the water had risen to within about two feet of the surface of the land. When the pump was started again a great volume of water had to be taken care of. As there was considerable "head" above the mains, the water flowed much more rapidly than at ordinary times. The easterly main, marked VIII-O on the map, brought into the reservoir small flocculent orange colored masses which floated in the water and slowly settled. These masses had evidently been torn from the walls of the tile by the rush of water. Upon examination a similar growth was found in the ditch beside Willow Drive. A specimen was taken to Dr. E. B. Fred of the Agricultural Bacteriology Department who identified it as iron bacteria, chiefly *Leptothrix ochracea (chlamydothrix ochracea),* though several other forms were also present.

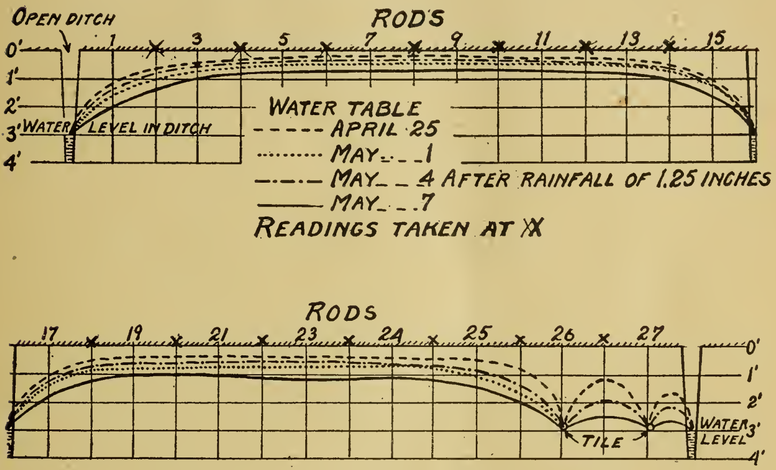


FIG. 13.—WATER TABLE TOO HIGH

Only near the open ditches or a line of tile is the water table where it should be—three feet below the surface.

As the growth of these organisms might have a very important bearing on the efficiency of the tile, the broken masses were traced to their point of growth. Two systems were found to be affected, both of them near the lake. Group VII, Lines 1, 2, 3, 4 and 5 were coated on the inside below the water line with masses that would average from ¼ to ¾ of an inch in thickness—principally along the sides. All these lines were of clay tile. Lines 6 and 7 of the same system containing cement tile showed no bacteria. Group VIII, Lines 1 to 6 containing clay tile were heavily infected with masses up to an inch in thickness. In Line 5 one mass was noticed 8 inches long and reaching up to the surface of the water (more than half the size of the tile) which was slowly moving down, pushed by the water behind it. On the other hand, no tile which came into the main from the south was infected. Neither was the main into which all tile emptied in common. The boundary between the infected area and the uninfected was clearly defined. Cement tile are inimical to these bacteria. So also is seepage from the upland. The bacteria were abundant where the seepage from the lake flowed through clay tile.

Harder* has done exhaustive research work on deposition of iron by various forms of bacteria. Ehrenberg in 1836 first discovered that bacteria were active in the depositing of iron. Harder groups the iron bacteria into three general classes: (1) those which extract carbon dioxide from ferrous bicarbonate and precipitate iron hydroxide in their cell walls; (2) those which do not require ferrous bicarbonate for their life process but precipitate iron hydroxide if soluble iron salts are present; (3) those which attack organic salts using the organic portion as a food and so precipitating the iron. Leptothrix belongs to the second class. Nearly all are what is known as "higher bacteria"—slender filamentous forms made of single elongated cells joined end to end. Some are flattened and double back on themselves forming a double spiral. Others are cylindrical and double back on themselves in a double spiral. but the greater number are single threads. All of them have the peculiar power of precipitating hydroxide of iron which later becomes oxidized and forms hydrated sesquioxide of iron which becomes bog iron ore. Leptothrix is primarily a soil organism and can grow without the assistance of iron compounds. Its habitat is, however, in bogs where iron is present in considerable quantity, some of it in the form of organic salts.

During the winter (1919-1920) the masses of bacteria in the tile in the marsh became much smaller but persisted in the ditch beside Willow Drive. In fact they grew faster there, probably due to a higher lake level and more abundant water. The masses in the tile grew again in the spring but in the summer of 1920 the main into which the infected tile emptied was lowered.

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*E. C. Harder, "Iron Depositing Bacteria and Their Geologic Relations."

In the process the laterals were dammed and drained several times and the rush of water cleaned them out. A month after work was finished the bacterial masses had again grown to considerable size.

There may be many places where tile are laid in a constant flow of water, that these organisms will give considerable trouble. In localities where this occurs it seems best to lay the laterals so that they may have a short sharp run to the main or to lay out the system in a way to let each lateral catch some upland water. A temporary cure for iron bacteria would be a small application of copper sulphate. Care should be taken that the amount of the chemical used is not enough to kill fish in the stream or lake into which the drains empty. Trout die if copper sulphate is used stronger than .14 parts per million while it takes .2 and .3 parts per million to kill leptothrix. Pickerel, perch and black bass, however, in the order named, can endure copper sulphate in strengths ranging from .4 to 2.1 parts per million. By stopping a drain temporarily, a concentrated solution may be kept for a time in contact with the bacteria. Upon discharging this into a creek or lake, this solution becomes so diluted that even trout are safe.

## PUMP AND POWER MEASUREMENTS

Records of the amount of electricity consumed were made from May 9 to June 9, 1916, and again from October 24 to November 25, 1920. A tested meter was obtained from the Department of Electrical Engineering. In the 1916 test, 1760 kilowatt hours were consumed in 31 days; and in 1920, 1830 kilowatt hours were consumed in 32 days. In each case it averaged about 57 kilowatt hours a day for the whole period. The area drained is about 130 acres. At 2 cents a kilowatt hour the cost of power is approximately a cent an acre a day. During the 1920 test the rainfall amounted to 1.75 inches which fell as follows: October 26—.06; November 1—.68; November 6—.57; November 8—.15; and November 21—.27. From November 5 to 15 the power consumed averaged 92 kilowatt hours a day, but from November 15 to 18 it averaged only 23 kilowatt hours a day. In 1916 there were several 5 day periods when the power consumption was less than 40 kilowatt hours a day.

**Dry Weather Seepage**—On October 24, 1920, a detailed study of the operation of the pump was made from 6 a. m. to 6 p. m. On that day dry weather prevailed, so that the pumping represented the seepage, ten days after a rain of any consequence.

The pump is a 16-inch auger having a two-bladed impeller, each blade making 4 inches more than one-half of the circumference in length and having a 4½ inch lift in one-half revolution or 9 inches in a whole revolution. The drive pulley is 16 inches. The motor is a 3 phase, a. c. 10 h. p. and has an 8-inch drive pulley. The shafts are set about 12 feet apart, and there is a quarter turn in the belt from the horizontal motor to the vertical pump shaft. The motor has ample power to drive the pump and the speed remained constant at 600 r.p.m.

The water was measured as it ran away from the pump over a 34-inch weir. It required 13 seconds after the starting of the pump before the water flowed over the weir, which it did with a rush. At the end of each run the pump continued to operate and the water to flow over the weir for a period of 4 seconds after the throwing out of the switch. As the water over the weir died down from full flow to nothing, it was assumed that the actual flow was equal to the average flow for half the time or 2 seconds. The effective run of the pump was therefore 11 seconds less than the actual time between the opening and the closing of the switch.

The pump started and stopped 39 times in 12 hours. It ran a total of 6,252 seconds. Subtracting 11 seconds for each of the 39 runs leaves 5,823 seconds of effective pumping or about 2½ minutes at a run. The average head over the 34-inch weir was .55 feet. For 5,823 seconds this gives a discharge of 22,457 cubic feet for the 12 hours. The current consumed was 10 kilowatt hours in the 12 hours or 20 kilowatt hours per day.

The elevations ascertained were as follows:

| | |
|---|---|
| Level of lake (feet above sea level) | 848.92 |
| Level of weir (feet above sea level) | 849.34 |
| Top of water when pumping (feet above sea level) | 849.89 |
| Height of water at start of pump (feet above sea level) | 843.43 |
| Height of water at stop of pump (feet above sea level) | 841.93 |
| Height of water at end of back lash (feet above sea level) | 842.70 |
| Height of water over weir (feet) | .55 |
| Head over pump at start (feet) | 6.46 |
| Head over pump at stop (feet) | 7.96 |
| Average lift for the day (feet) | 7.21 |

Every time the pump stopped, 85.8 cubic feet of water ran back through the pump into the reservoir. In 39 runs this amounted to 3,346 cubic feet which was wasted. It amounted to 15 per cent of the water that went over the weir. Since this water was lifted to a height averaging only one-half that of the water that went over the weir, the waste of energy is only 7½ per cent. During periods of heavy pumping when the run of the pump is 6 or 7 minutes, the percentage of waste is less than that.

The total effective inlet of the pump is its cross-sectional area of the pump minus the area of its hub or $(0.67^2 x 3.1416)$—$(0.16^2 x 3.1416)=1.33$ sq. ft. The lift being 9 inches and the speed 10 revolutions per second, the volume described by each revolution of the pump is 1.33x.75x10=9.97 cu. ft. per second, as compared with an actual discharge of 3.85 cubic feet per second. It would seem that the speed of the pump might be considerably reduced without cutting down its efficiency.

TABLE III.—SOURCE OF SEEPAGE

| System | Acres drained | Cu. ft. discharge in 12 hrs. | Discharge per acre per day | Inches from area in 24 hrs. | Remarks |
|---|---|---|---|---|---|
| 15-in. main | 80 | 2,430 | 60.75 | .0156 | Underlaid by clay |
| 8-in. main | 13 | 10,627 | 1,634.92 | .45 | Main and laterals deep in sand |
| Balance of tract | 37 | 9,400 | 509.46 | .14 | Includes reservoir at pump house and 20 acres not tiled |

**Areas Supplying Seepage Water.**—In order to ascertain where this water was coming from, a 9-inch weir was put in at the mouth of the 15-inch main and an 8-inch weir on Main VIII, 20 feet below the triple junction at Station 7+49. The measurements are shown in Table III. The average acre near the lake had about 27 times as much seepage as the average acre in the 80-acre tract drained by the 15-inch main. Near the lake the seepage amounted to .45 inches a day while farther away it was only .0156 inches.

TABLE IV.—DAILY AMOUNT OF WATER PUMPED IN SECOND-FEET AND ACRE-INCHES

| Date | Period pumped in minutes | Rainfall inches | Average lift | Water pumped | |
|---|---|---|---|---|---|
| | | | | Rate second-feet | Acre-inches per day |
| 1914 | | | | | |
| April 20 | 448 | ---- | 1.78 | 14.1 | 105.2 |
| 21 | 940 | ---- | 3.42 | 4.6 | 68.7 |
| 22 | 575 | ---- | 3.74 | 3.21 | 31.0 |
| 23 | 735 | 0.03 | 4.46 | 1.2 | 14.7 |
| 24 | 305 | 0.87 | 4.50 | 1.82 | 9.22 |
| 25 | 320 | ---- | 4.51 | 2.47 | 13.2 |
| 26 | 155 | ---- | 4.17 | 1.44 | 3.7 |
| 27 | 130 | 0.23 | 4.63 | 1.44 | 3.14 |
| 28 | 325 | 0.36 | 4.51 | 1.59 | 8.6 |
| 29 | 210 | 0.05 | 4.58 | 1.96 | 6.85 |
| 30 | 180 | 0.01 | 4.37 | 2.47 | 7.41 |
| May 1 | 135 | ---- | 4.72 | 1.34 | 3.02 |
| 2 | 205 | ---- | 4.32 | 1.80 | 6.14 |
| 3 | 305 | 1.26 | 4.05 | 2.16 | 10.8 |
| 4 | 370 | ---- | 4.18 | 2.47 | 15.2 |
| 5 | 360 | ---- | 4.54 | 3.36 | 20.16 |
| 6 | 510 | ---- | 4.61 | 2.47 | 21.0 |
| 7 | 225 | 0.05 | 4.59 | 3.36 | 12.6 |
| 8 | 350 | ---- | 4.71 | 1.82 | 10.62 |
| Totals | 6,783 minutes | 2.86 inches | ---- | ---- | 371.5 acre-inches |

**Measurements in 1914.**—Table IV shows the amount of water that was lifted about 5 feet by a 16-inch reverse-turbine pump driven by a 12 h. p. gasoline engine in 1914. At that time about 20 acres of the higher marsh were tiled but only ¼ acre of the lake-level marsh was tiled. The rest of it was drained by 880 rods of open ditches 4 feet deep. The pumping amounted to 20 acre inches a day or about .16 inches from the entire area. In the 19 days this amounted to 3.04 inches as compared with a rainfall for that period of 2.86 inches.

The discharge of the pump was measured by a weir 5 feet wide. The head of the weir was read at intervals during the pumping period and averaged to compute the discharge. The lift was also recorded at intervals and averaged. The discharge of the pump was much greater for the low lifts, but the power required was also greater.

The height of the water in Lake Mendota varies as much as 3 feet. On June 1, 1919, it rose to 851.90, according to the city engineer of Madison. It has been as low as 848.5. At such low water periods the flash boards of the spillway of the pump are taken out to reduce the lift.

## HEIGHT OF WATER TABLE

During the pumping test in 1914, observations were made upon the height of the water table at intervals of 1 rod between the open ditches and the two lines of tile that were laid. The results are shown in Figure 13. The rainfall during the period is shown in Table IV. At each observation pit, four

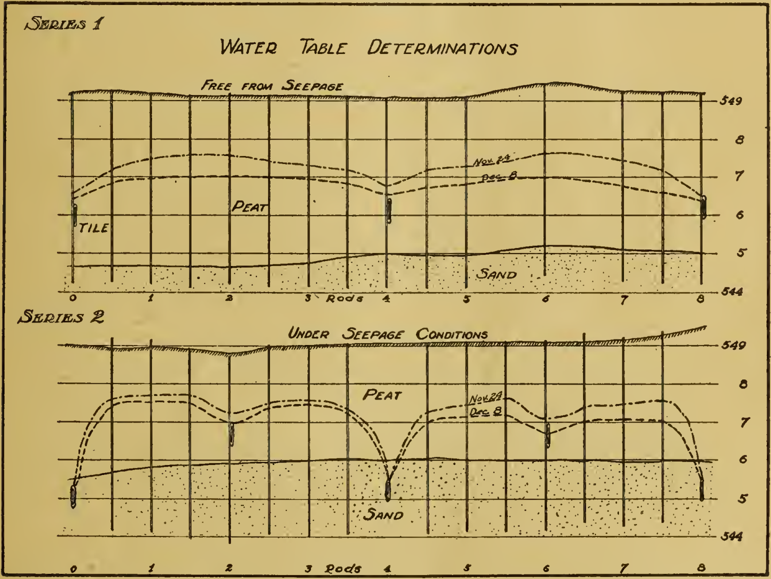

FIG. 14.—BETTER, BUT STILL TOO WET

In Series 2, the shallow tile belong to the original system. The deeper lines were installed later. Note how the deep, rather than the shallow tile, affect the water table.

5-inch tile were placed in a vertical column in a hole, the top of the upper tile reaching about to the surface of the ground and being used as a reference point in reading the height of the water in the hole. Even on May 7 when the water table was 1 foot below the surface, the land was too soft to hold up the horses.

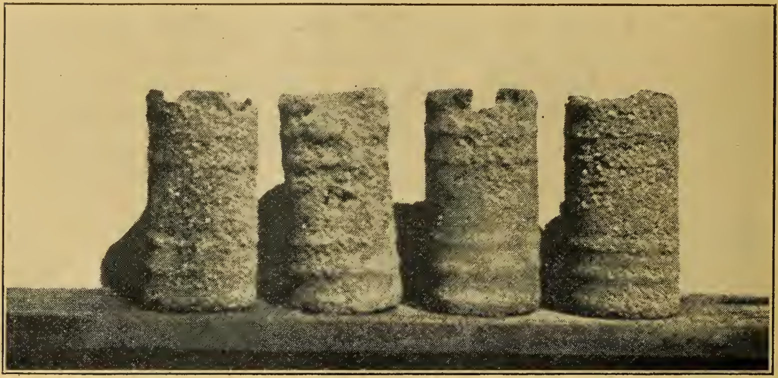

FIG. 15.—POOR CEMENT TILE FAIL

This tile was made too porous. It had been laid in a high lime muck for 4 years when this picture was taken.

Another set of observations began in November, 1920. In each hole five 5-inch tile were placed in a vertical column, the bottom of which reached to the sand in each case. Figure 14 shows the results to date. During this period the soil was dry and firm enough at the surface to hold up horses or tractors.

A peculiar feature of the observations now in progress is that the water table directly over a line of tile is in some places from 4 to 8 inches higher than the top of the tile, yet the tile were not more than half-full of water which ran swiftly in every case. This is probably due to the pressure of water from below and the slowness with which the water moves through the peat. It appears, however, that at Hole IX Series B where the tile are only 2 feet deep, the water table is as much above the tile as at Hole IX Series A where the tile are more than 3 feet deep. Even under these conditions the deep tile are the more efficient. At A, B and C the tile had just been deepened and the looseness of the peat over the tile accounts for the low water table there.

## INVESTIGATIONS WITH CEMENT TILE

Several lots of cement tile were laid on the University Marsh. At the time they were purchased and laid they were thought to be the best cement tile available. Nevertheless, many of them were badly disintegrated or had totally collapsed at the end of six years. The action of the acids of the peat is the most probable cause of the distintegration. On the other hand, some good but not extra quality cement tile laid in the neutral peat on the University Marsh in October, 1919, had roughened but little by August, 1921, and were stronger than when laid.

Some cement tile manufacturers are now making an extra quality tile with walls so dense that the absorption of water is kept below 10 per cent after 5 hours of boiling. The following are the minimum wall thicknesses:

4-inch tile 5/8″ thick
5-inch tile 11/16″ thick
6-inch tile 3/4″ thick
8-inch tile 13/16″ thick
10-inch tile 7/8″ thick
12-inch tile 1″ thick

Decreased wall thicknesses may be compensated for by increasing the density, but it has not yet been proven that they will stand up in an acid peat, unless the peat is underlaid with clay in which the tile are imbedded. In such peat, and in most clays in Wisconsin, extra quality cement tile are satisfactory. For beds of acid peat underlaid by sand, or those so deep that the tile are not imbedded in the underlying clay, it is best for the present to give preference to good hard burned shale or clay tile even at the expense of high freight rates on such tile.

The findings on the University Marsh substantiated by similar findings in 20 cases in 10 counties in Wisconsin should be a solemn warning to the manufacturers of poor cement tile. The poorest cement tile have been made with small machines by farmers themselves. But little better than these are the cement tile made by the small plants not equipped with good workmen, good materials or a steam curing device.

## DRAINED PEAT BURNS

In August 1919 during a dry period, a careless workman dropped a lighted match on the area drained by Group III. By the next morning about two acres had burned over, burning the peat to depths varying from 6 to 12 inches. The pump was stopped and the water from the lake was allowed to run back to put out the fire. Due to the buoyancy of the soil and the dense dry grass on the surface, it was difficult to immerse all parts of the burning marsh and it took two days to put out the fire. By that time about 4 acres had burned more or less. Usually the ashes from burned peat helps the next year's crop by making the potash more available, but for reasons as yet unexplained, the crop of corn on these four acres in 1920 was poorer than in the unburned area.

## COST OF DRAINAGE

**Open Ditches**—Most of the ditching crew were student laborers.

The original ditches 1 foot wide at the bottom, 4 feet deep and 5 feet wide at the top were dug by hand. Men were paid $2.00 a day and the average cost of the ditches was 90 cents a rod, for the 880 rods. For about 100 rods the ditches reached through the peat and one foot into the underlying clay. This increased the cost. Where no willow roots bothered and the peat was 4 feet deep, the cost was only about 75 cents a rod. The peat was cut with hay knives or spades into blocks containing about 1 cubic foot and then heaved out with manure hooks.

While these ditches did not dry the land enough to prevent horses from miring, they did make the soil firmer. It would have been difficult or impossible to lay the tile subsequently had not these ditches been put in first as fore-runners. They made the soil firm enough so that the trenches stood up well while the tile were being laid, and even permitted the use of a caterpillar tiling machine, although the tile had to be carried 40 rods or more by hand, except on Plot S where a caterpillar tractor was used to draw light loads of tile on a wagon.

**Protecting Ditch and Dike**—Available roads were used as dikes.

The ditch and dike at the north side of the marsh was made about 2½ feet deep and 10 feet wide at the top. The earth excavated was used to make a dike about 2½ feet high in the lower side. The work was done with teams and scrapers during May 1910, when the ground was so wet that horses walked in the ditch with difficulty, sinking to their fetlocks in the soft clay. Here there was no peat at all on the surface and large boulders imbedded in the clay had to be blasted before they could be handled. The cost of this ditch was 55 cents a rod, figuring a team and driver worth 40 cents an hour, and a laborer 20 cents an hour.

**The Pumping Plant**—This includes no subsequent repairs.

The cost of the pumping plant including 2000 feet of transmission line, two 10 h.p. motors with transformers, and automatic devices; the pump house with two pumps completely installed, was about $2,200.

**The Tile**—This does not include surveying nor supervision.

The mains and sub-mains into which the laterals discharge aggregate 90 rods of 15-inch, 110 rods of 12-inch, 42 rods of 10-inch, 320 rods of 8-inch and 345 rods of 6-inch tile. The total cost of these was $3,100. The laterals are 8 rods apart on approximately 30 acres, 4 rods apart on 60 acres, and 2 rods apart on 40 acres, with about 1 acre that had to have lines 1 rod apart to dry up all of the persistent springs. These aggregate about 6,300 rods or nearly 20 miles and cost approximately $8,000. All but 5 carloads of tile were bought and laid at pre-war prices.

**Cost Per Acre**—The total cost of the drainage system may be itemized as follows:

| | |
|---|---|
| Open ditches (later filled) | $790.00 |
| Protecting ditches and dikes | 170.00 |
| Pumping plant | 2,200.00 |
| Tile mains | 3,100.00 |
| Tile laterals | 8,000.00 |
| Total | $14,260.00 |

This brings the average cost approximately $110 an acre for the 130 acres. The unusual seepage from the lake and through the underlying sand from the surrounding hills together with the pumping made the drainage of this marsh about 100 per cent more difficult than the average marsh land in Wisconsin. Nevertheless, it was profitable because of high land values adjacent to the University Farm.

## CONCLUSIONS

1. The shrinkage of peat above the tile is such that tile may have to be relaid in from 10 to 20 years.
2. Tile 3 feet deep are too shallow. Tile 4 feet deep and 8 rods apart are more efficient than tile 3 feet deep and 4 rods apart. The most efficient tile in the deep peat or where seepage is great are those 5 feet deep acid peats.
3. Well-made cement tile are satisfactory in clay sub-soils and none but the best should be tolerated in any soil.
4. Peat disintegrates some cement tile. It has not yet been proven that even the best of cement tile will stand up in acid peats, unless imbedded in underlying clay.
5. The pump should be started before the tops of the tile outlets are submerged.
6. Where the reservoir is small the pump must be started at frequent intervals. An automatic starter takes the place of a constant attendant. Electricity lends itself to automatic control better than gasoline, steam or wind.
7. A simple auger pump that permits sticks and debris to pass through it without clogging or binding is most satisfactory.
8. An emergency pump for use in case of accident or unusual floods should be kept ready for action.
9. About ½ kilowatt-hour of power is the average used per acre in 24 hours to lift the water 7 feet. The minimum was ⅙ kilowatt hours per acre per day.
10. The dry weather seepage amounts to about .1 inch in 24 hours. The maximum requirement has been about .8 inches in 24 hours from the entire area.

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